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RWF ROTOR-WAKE-FUSELAGE CODE SOFTWARE REFERENCE GUIDE

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Table of Contents

RWF

Rotor–Wake–Fuselage Code

1 Introduction

The **RWF** computer code has been developed from first prinicples to compute the aerodyamics associated with the complex flowfield of helicopter configurations. The code is sized for a single, multi-bladed main rotor and any configuration of non-lifting fuselage.

1.1 Document Organization

This reference guide is organized into the following sections:

1. Introduction
2. Methodology
3. Types of Data Files
4. Input File Preparation
5. Sample Output
6. Installation Notes
7. Cautions

1.2 Notational Conventions

The following notational conventions are used in this reference guide.

- File names will be indicated by **bold face** type.

  EXAMPLE: **wingd.inp** is the input file.

- Literal input and output are indicated with `teletype face` type.

  EXAMPLE: `NSTEP` specifies the number of time steps.

- Characters which may have several values will be indicated by a *slanted face* type.

  EXAMPLE: **cnx.dat** one of these files is created for each blade, the blade index is put in *x*.

1.3 Software Environment

Although developed under a UNIX operating system environment, two system specific routines are used to reduce the system of linear equations. The vector library routine which is used can be replaced by a method provided in the source module library. See section on Installation Notes for configuration.

The program is designed for batch operation, requiring a file containing "namelist" formatted input of the control variables, a file with tabulated values for the body geometry, and an optional file containing field points for velocity calculations. Several output files are produced; one containing the load and program control information; an optional field velocity file; and a series of azimuthal step-specific geometry files.

2 Methodology

The mathematical model for the Rotor Wake Fuselage code is based on the integration of the momentum equations and Green's theorem. The unknowns in the problem are the strengths of prescribed singularity distributions on the boundaries of the flow. For the body (fuselage) a surface of constant strength source panels is used. The following figure shows an example helicopter fuselage configuration and its panel representation.

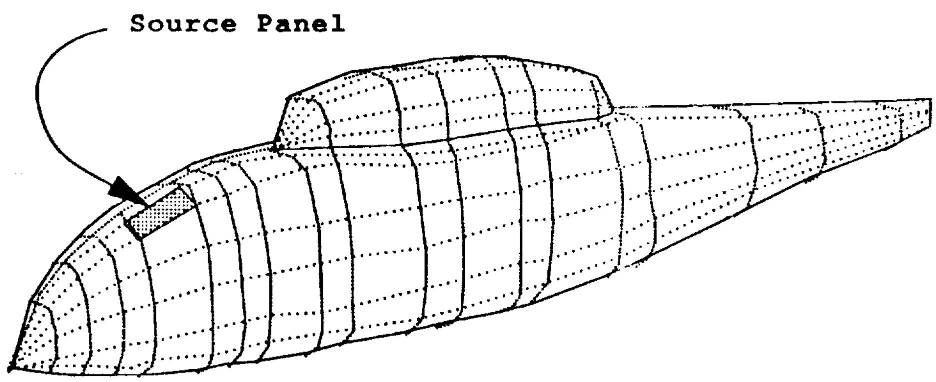


Figure 2.1: Fuselage Configuration

For the rotor blades and rotor wake a surface of constant strength doublet panels is used. The mean camber line of the rotor airfoil is partitioned into surface panels. The no-flow boundary condition at the panel centroids is modified at each azimuthal step to account for rotor blade cyclic pitch variation. In the figure below the surface and wake panel configuration of a typical rotor blade is shown in schematic.

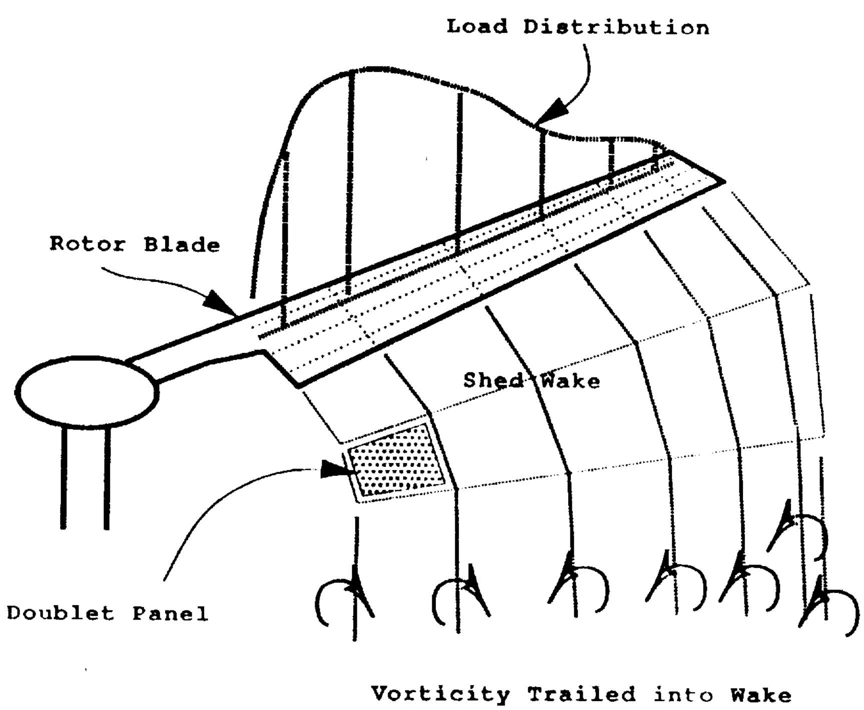


Figure 2.2: Rotor Blade and Wake Panel Configuration

The program solves the fully unsteady aerodynamics by time stepping a solution using quasi-steady approximations to the flow. The initial geometry of the rotor wake includes only a single downstream row of doublet panels which represent the rotor wake. The solution procedure impulsively start the rotor and at each successive time step the rotor blade sheds a new downstream row of doublet panels.

The strengths of the surface singularities are found by solving the system of linear equations which form the boundary condition of no normal component of velocity at the panel centroids. By forcing the normal component of velocity at each of the panel centroids to be zero, the distribution of singularity strengths can be determined. Knowing the distribution of singularity strengths, the velocity field at any point in the flow can be determined.

The solution to the system of equations is made in a series of time steps by advancing the rotor system through successive azimuthal steps and moving the geometry of the rotor and body forward in the fluid. At each successive time step the elements of the influence matrix change due to new panel geometry. The geometry of the wake is computed at each time step by computing a convection velocity at each wake node and multiplying by the length of the time step. This new wake geometry is used to calculate the known portion of the velocities contributing to the flow at each panel centroids.

3 Types of Data Files

All data files used by **RWF** are ASCII character files. The following table describes the files used by this program:

3.1 Input Data Files

- **wingd.inp** or **WINGD.INP** This is the "NAMELIST" file for input. The namelist used for input to **RWF** is labled CHANGES.

- **BODY.HES** This file is used to input the geometry of the fuselage. The coordinates of the fuselage are entered using the format described below. No optional parameters are used and columns 79 and 80 may be blank. Only columns 1 through 32 are read.

- **GRID.DAT** This file establishes points for field velocities to be calculated. The format is unstructured with the first record containing an integer number for the number of points (succeeding records) to be used. Each "point" record must contain the x, y, z coordinates of the field points to be computed. These coordinates are in rotor radius reference length, with a coordinate system centered on the hub center, oriented in the tip path plane, x oriented downstream (tailward), y oriented off the right side of the forward-facing pilot, and z (as expected) oriented up.

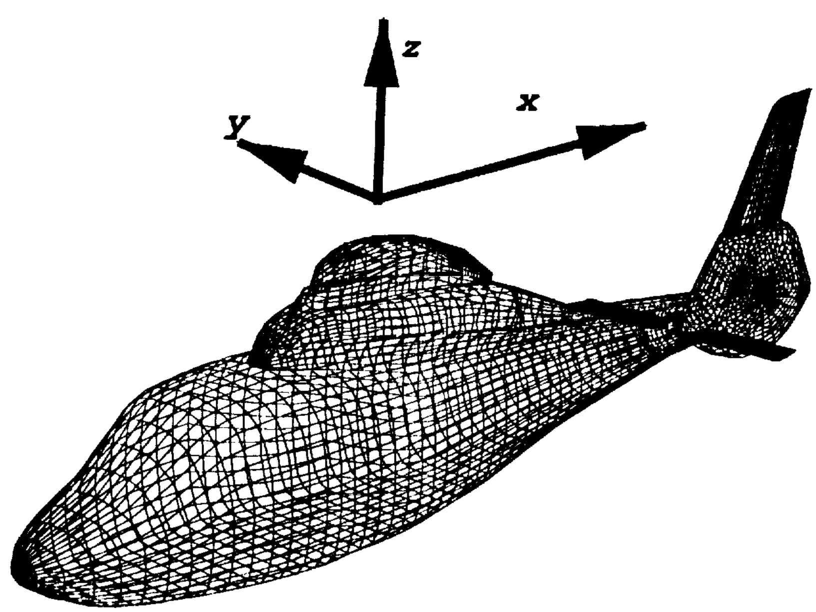


Figure 3.1: Coordinate System

3.2 Output Data Files

- **stdout** or **FOR006.DAT** This file (or output stream) is used to list the program outputs. This output includes the initial geometry of the rotor and body, as well as the computed singularity strengths at each time step of the solution. The rotor loads are also included in this output.

- **cn0.dat** or **CN0.DAT** This file contains a summary of the normal force coefficients along the index rotor blade as a function of azimuth. The radial load distribution is output at interpolated sections controlled by selection of stations in the `CHANGES` namelist.

- **cnx.dat** These files list the normal force coefficients for each of the rotor blades (1 to x) as a function of blade geometry panel radii and azimuth.

- **comami.PLT** These files are output at azimuth step increments controlled by a parameter in the `CHANGES` namelist. The geometry of the rotor, its wake, and the body are included in this file as well as the computed surface pressure, C_P, local velocities, and singularity strength.

- **GPVEL.DAT** This file returns the field velocities calculated at the points established by **GRID.DAT**. The initial points are translated with the center of the hub, if the input variable `INERTIAL` is false. Otherwise the grid points stay at their inertial locations as the solution marches in time (and space.) The velocities are output in the same sequence as the field points are specified, with each azimuthal step prefaced by a "zone" separator record.

3.3 Debug Files

- **geom.dbg** This file contains the controlling parameters for each panel of the system.

- **matrix.dbg** This file contains all the elements of the coefficient matrix for the rotor.

3.4 Geometry File Format

The format for all geometry files is a sequence of 80 column records containing:

1. columns 1—30: three 10-character floating point numbers, X, Y, Z.

2. columns 31 and 32: two 1-character integer numbers, K_i, K_j, indicating beginning-of-strip/beginning-of-element and component code reapectively. K_i is 2 to indicate the first point in a new element, or 1 to indicate the first point in a new strip. K_i is 0 otherwise. Each strip in an element must have the same number of panels. The component code, K_j is read, but not used by this release of the code.

3. columns 33—72: up to four additional 10-character floating point numbers for optional parameters, P_1, P_2, P_3, P_4. The number of fields must coordinate with the number in column 80.

4. columns 73—78: blank filled.

5. column 79: one character code (blank, +, or -) to show the interpretation of the additional floating point numbers. A blank in this column means to interpret the additional parameters

at the coordinate in this line. A + indicates that the parameters are to be interpreted at the center of the panel that this coordinate begins. A - indicates that the parameters are to be interpreted at the center of the panel that this coordinate ends.

6. column 80: 1-character integer number (1—4) indicating the number of additional parameters to use. This number should be constant for the entire file.

4 Input File Preparation

Up to three (3) input files must be prepared for the **RWF** code.

1. Main Control File
2. Body Geometry File
3. Field Velocity Points File

4.1 Control File

The main control file is in the form of an ASCII "namelist." The name of the FORTRAN namelist is `CHANGES`. The elements included in the list for `CHANGES` are tabulated below. The table includes the type of variable needed for the element and the default.

Input File Variables			
Element	Type	Default	Description
HOVER	LOGICAL	.FALSE.	Use hover conditions
CLIMB	LOGICAL	.FALSE.	Use climb conditions
FORWRD	LOGICAL	.TRUE.	Use forward flight conditions
COSINE	LOGICAL	.FALSE.	Use Cosine distribution of chordwise panels
TWIST	LOGICAL	.FALSE.	Apply specified twist to blades
RLAMDC	REAL	0.0	Ratio of climb speed to tip speed
RLAMDF	REAL	0.18	Ratio of forward speed to tip speed
GAMINC	REAL	10.	Incidence of tip-path-plane to forward flight
SPANB	REAL	0.767	Length of inner blade portion
SPANW	REAL	0.30	Length of outer blade portion
CHOR	REAL	0.108	Chord width
RO	REAL	0.05	Length of root cutout
BETAW	REAL	0.0	Dihedral of outer blade portion
RPM	REAL	300.	Rotor RPM
ATACK	REAL	8.5	Blade pitch at 3/4 radius
PSIO	REAL	0.	Initial index blade azimuth
NC	INTEGER	6	Number of chordwise panels
M	INTEGER	21	Number of spanwise panels
NBLAD	INTEGER	14	Number of panels on inner portion
NWINGL	INTEGER	6	Number of panels on outer portion
CORE	REAL	0.3	Ratio of Vortex filament core to outer panel width

Table 1. Input File Variables

Input File Variables (continued)			
Element	Type	Default	Description
DPSIDG	REAL	30.	Size of time steps in degrees
NSTEPS	INTEGER	36	Number of time steps
TEWT	REAL	-10.0	Blade twist, root to tip
TAPER	REAL	1.0	Ratio of outermost chord to inner chord
TAPST	REAL	0.0	Non-dimensional radius to start taper
APLT	REAL	90.	Azimuth increment to generate plot files
AZEROD	REAL	0.0	Coning angle in degrees
BAONED	REAL	0.0	Lateral cyclic pitch in degrees
BBONED	REAL	0.0	Longitudinal cyclic pitch
DEBUG	LOGICAL	.FALSE.	Flag for debug files
INFLOW	LOGICAL	.TRUE.	Flag to use interactive wake inflow
XHUB	REAL	0.685	Rotor hub x dimension in body coordinates
YHUB	REAL	0.0	Rotor hub y dimension in body coordinates
ZHUB	REAL	0.4074	Rotor hub z dimension in body coordinates
RFUS	REAL	1.0	Radius in body dimensions
AFUS	REAL	2.0	Angle of attack of the body
RHOO	REAL	0.002378	Density of air
RCALC	REAL	Array*	Array of radial positions to print loads
ROTOR	LOGICAL	.TRUE.	Flag to compute rotor effects
FUSELAGE	LOGICAL	.FALSE.	Flag to compute body effects
DOGRID	LOGICAL	.FALSE.	Flag to compute field velocities
FSTEP	LOGICAL	.FALSE.	Flag for variable step size (not implemented)
INERTIAL	LOGICAL	.FALSE.	Flag for output to be in inertial or hub coordinates
* The first element of the array is the number of entries to follow			

Table 1. Input File Variables (concluded)

4.2 Input Variable Considerations

Modifying the **wingd.inp** file requires consideration of the effects of each of the variables in **CHANGES**. The following list gives considerations for each of the elements of **CHANGES**.

HOVER If **TRUE** then no initial forward flight wake vortex trailing elements will be added to the beginning of the wake. The onset velocities will be set to zero.

CLIMB If **TRUE** then **RLAMDC** is used for the z component of onset velocity. The x and y components are set to zero.

FORWRD If **TRUE** then the onset velocities are computed from **RLAMDF** and **GAMINC**. To prime the inflow velocity pump, two semi-infinate vortex filament "trailers" will be attached to the inertial $\Psi = 90$ and $\Psi = 270$ locations for the rotor disk and extended in the downstream direction. In more than one of **HOVER** or **CLIMB** or **FORWRD** are **TRUE** then an error condition is set and the program aborts.

COSINE If **TRUE** then the chordwise distribution of panels follows the cosine distribution rule; if **FALSE** then a uniform distribution is used.

TWIST If **TRUE** then the blade geometry is generated with a linear twist distribution governed by **TEWT**.

RLAMDC Ratio of climb speed to tip speed.

RLAMDF Ratio of forward speed to tip speed.

GAMINC Angle of attack of the tip-path-plane to the onset flow.

SPANB Radial length of the main blade span, from root cutout to joint with the tip element, in length units.

SPANW Radial length of the blade tip span, from joint with the main blade element, in length units.

CHOR Width of blade (at root if tapered), in length units.

RO Radial length of root cutout, distance to first effective blade chord from center of hub, in length units.

BETAW Anhedral (+) or dihedral (−) of blade tip dimensioned above, in degrees.

RPM Revolutions per minute of the rotor. This determines the dimensional speed of the rotor tip.

ATACK Effective angle of attack of the blade three-quarter radius, collective pitch, in degrees.

PSIO Starting azimuth of the reference (number one) blade.

NC Number of chordwise lines, (one more than the number of chordwise panels.)

M Number of radial lines, (one more than the total number of radial panels.)

NBLAD Number of panels on the main blade section.

NWINGL Number of panels on the blade tip section. (The sum of **NBLAD** and **NWINGL** must be one less than **M**.

CORE Effective minimum radius of the vortex filament elements used in the vortex lattice representation. It is given as a factor of the radial dimension of the outermost blade panel.

DPSIDG Size of azimuthal steps, in degrees.

NSTEPS Number of azimuthal steps, or ultimate number of trailing wake panels.

TEWT Effective linear twist of each rotor blade, in degrees, tip pitch minus root pitch.

TAPER Ratio of tip chord to root chord.

TAPST Non-dimensional radial distance to begin taper.

APLT Azimuthal increment for generating plot data files.

AZEROD Coning angle, in degrees.

BAONED Longitudinal cyclic pitch, in degrees.

BBONED Lateral cyclic pitch, in degrees.

DEBUG If **TRUE** then "debug" files containing panel coeffeicients and elements of the coefficient matrix are generated.

INFLOW If **FALSE** then the effective blade panel angles of attack are produced from the UTRC generalized wake model, the convected wake induced velocities are not used.

XHUB In ratios of rotor radius, the x dimensional offset of the rotor hub from the fuselage 0 station.

YHUB In ratios of rotor radius, the y dimensional offset of the rotor hub from the fuselage centerline.

ZHUB In ratios of rotor radius, the z dimensional offset of the rotor hub from the fuselage 0 waterline.

RFUS Radius of the rotor in fuselage coordinates. (Scales the fuselage coordinates to the rotor coordinates.)

AFUS Angle of attack of the fuselage waterline relative to the tip-path-plane, in degrees, (+) is nose up.

RHOO Nominal density of the fluid, in slugs per cubic foot.

RCALC An array of radial stations to output rotor loads. The first element of the specified array is to be the number of array elements to follow.

ROTOR If **FALSE** then the solution for the rotot and wake is not computed, the process terminates after the solution for the fuselage in freestream.

FUSELAGE If **FALSE** then only the isolated rotor and wake solution are produced, no input of body geometry is done.

DOGRID If **TRUE** then the field velocity point geometry file is read and the induced velocities at these points are computed and output. The geometry file must be specified in rotor radius length ratios.

4.3 Input File Namelist Example

The following file is an example of a "NAMELIST" input file format. The only elements needed in the input file are those differing from the default values in the program. This namelist is read from the file **wingd.inp**.

```
 $CHANGES
 ROTOR = .T.,
 FUSELAGE = .T.,
 DOGRID = .T.,
 INERTIAL = .T.,
 TWIST = .T.,
 RLAMDC= 0.0,
 RLAMDF= 0.2300,
 GAMINC= -3.0,
 TEWT  =-6.052,
 TAPST = 0.,
 TAPER = 1.,
 SPANB = 1.5000,
 SPANW = 0.635833,
 CHOR  = 0.2175,
 RO    = 0.6875,
 BETAW = 0.,
 PSIO  = 0.,
 NC    = 3,
 M     = 12,
 NBLAD = 7,
 NWINGL= 4,
 CORE  = 0.3,
 DPSIDG= 10.,
 NSTEPS= 15,
 APLT  = 10.,
 RPM   = 2110.5,
 ATACK = 7.586,
 BAONED= -.80,
 BBONED= 3.75,
 XHUB = 0.685,
 ZHUB = 0.3189,
 AFUS = 2.5,
 RFUS = 0.847,
 INFLOW = .true.,
 DEBUG = .false.,
 COSINE = .false.
 $END
```

Listing 1. Example File **wingd.inp**

Notice that the file format requires a space character before the $ in the first and last lines.

The example files in the following section will be from an example run using the file listed above.

5 Sample Outputs

```
 enter namelist changes (WINGD.INP):
$changes
hover =   F
climb =   F
forwrd =   T
cosine =   F
twist =   T
rlamdc =  0.0000000E+00
rlamdf =  0.2300000
gaminc =  -3.000000
spanb =  1.500000
spanw =  0.6358330
chor =  0.2175000
r0 =  0.6875000
betaw =  0.0000000E+00
rpm =  2110.500
atack =  7.586000
psi0 =  0.0000000E+00
nc =             3
m =            12
nblad =             7
nwingl =             4
core =  0.3000000
dpsidg =  10.00000
nsteps =            15
tewt =  -6.052000
taper =  1.000000
tapst =  0.0000000E+00
aplt =  10.00000
axerod =  0.0000000E+00
baoned =  -0.8000000
bboned =  3.750000
debug =   F
inflow =   T
xhub =  0.6850000
yhub =  0.0000000E+00
zhub =  0.3189000
rfus =  0.8470000
afus =  2.500000
rho0 =  2.3779999E-03
rcalc =  7.000000, 0.2500000, 0.4000000, 0.5500000, 0.7500000, 0.8500000,
         0.9000000, 0.9500000, 1.000000, 1.000000
rotor =   T
fuselage =   T
dogrid =   T
fstep =   F
inertial =   T
$end
 Geometric induced velocity is   5.5482984E-02
```

Geometric thrust is 142.7538

1 4 BLADE ROTOR IN FORWARD FLIGHT ADVANCE RATIO= 0.2300

ROTOR INCLINATION ANGLE= -3.00

Non-dimensional velocity is: 0.2300000

CORE FACTOR= 0.300E+00

ANGULAR STEP= 10.00 DEGREES

AR= 12.981 SPAN,CHOR,RAD= 2.136 0.218 2.823

ATTACK(DEG)= 7.59 RPM= 2110.5 OMINF(RAD/S)= 221.01 VO(U/S)= 623.99

NO. OF PANEL ROWS ON BLADE= 3 NO. OF LINE VORTEX COLUMNS ON BLADE= 12

VORTEX LATTICE POINTS,XB(I,J) J=1,M YB(I,J) J=1,M,ZB(I,J) J=1,M, I=1,NC+1

Fuselage input will be multiplied by 1.180638

File opened...

End of input.

Body geometry input: 552 panels.

Element	Strips	Panels
1	30	8
2	30	8
3	9	4
4	9	4

Fuselage Source str. due only to free-stream

0.0196	0.0216	0.0243	0.0240	0.0210
0.0216	0.0215	0.0214	0.0031	0.0061
0.0124	0.0165	0.0186	0.0194	0.0192
0.0191	-0.0127	-0.0078	-0.0016	0.0040
0.0073	0.0085	0.0087	0.0079	-0.0118
-0.0074	-0.0024	0.0030	0.0056	0.0085

Extended list of source strengths abbreviated

-0.0047	-0.0100	-0.0092	-0.0241	-0.0236
-0.0255	-0.0252			

SETROT sent (no length): 0.0000000E+00 0.0000000E+00 0.0000000E+00

Time to solve 132 matrix is 0.0000000E+00

VORTICITY DISTRIBUTION ON BLADE SURFACE GAMA/(OMEGA*R**2)

```
 0.24351    0.31940    0.39530    0.47120    0.54710    0.62300    0.69890    0.77479    0.86098    0.93404
 0.98286

 0.00769    0.01020    0.01155    0.01232    0.01264    0.01256    0.01210    0.01118    0.00962    0.00743
 0.00481
 0.00683    0.00900    0.01018    0.01084    0.01112    0.01106    0.01066    0.00986    0.00851    0.00663
 0.00434
 0.00509    0.00661    0.00746    0.00795    0.00815    0.00811    0.00782    0.00724    0.00627    0.00496
 0.00337
File cn0.dat              opening
File cn1.dat              opening
File cn2.dat              opening
File cn3.dat              opening
File cn4.dat              opening
 Enter Main Azimuthal Loop
Element           0
       Strip            1
          1 -0.1899512            2 -0.1866104            3
-0.1884925         4 -0.1937913            5 -0.2025066
          6 -0.2143665            7 -0.2317650            8
-0.2495881         9 -0.2654159
       Strip            2
          1 -0.1796682            2 -0.1628125            3
-0.1585249         4 -0.1588290            5 -0.1646063
          6 -0.1752910            7 -0.1956276            8
-0.2222647         9 -0.2545453
       Strip            3
          1 -0.1717356            2 -0.1443031            3
-0.1350209         4 -0.1312118            5 -0.1346387
          6 -0.1447358            7 -0.1674227            8
-0.2005235         9 -0.2457313
       Strip            4
          1 -0.1693852            2 -0.1387209            3
-0.1279696         4 -0.1229854            5 -0.1255309
          6 -0.1353342            7 -0.1586087            8
-0.1937660         9 -0.2430871
       Strip            5
          1  0.0000000E+00        2  0.0000000E+00        3
 0.0000000E+00     4  0.0000000E+00        5  0.0000000E+00
          6  0.0000000E+00        7  0.0000000E+00        8
 0.0000000E+00     9  0.0000000E+00


PSIAV=   10.0000 DEG     TEND=(R/B)*PSIAV=    0.1745        1 TIME STEPS

          Pressure Coefficients
Blade Loads (Chord stations)
Radius     Cn         0.16667   0.50000   0.83333
 Blade index           1
  0.28502   0.61696  -0.38835  -0.13762  -0.07463
  0.36017   0.72066  -0.55727  -0.20217  -0.10430
  0.43558   0.75332  -0.69190  -0.25207  -0.12905
  0.51113   0.75581  -0.80501  -0.29322  -0.14938
```

0.58677	0.74090	-0.89831	-0.32673	-0.16580
0.66247	0.71384	-0.97131	-0.35243	-0.17814
0.73821	0.67637	-1.02168	-0.36916	-0.18564
0.81912	0.62326	-1.04382	-0.37380	-0.18611
0.89863	0.54572	-1.00944	-0.35282	-0.17191
0.95950	0.43239	-0.87646	-0.28481	-0.13312
0.99245	0.28298	-0.62420	-0.17116	-0.07967

Ct/s = 0.1121358

Blade index 2

0.28502	0.26830	-0.27451	-0.09150	-0.04534
0.36017	0.27311	-0.31444	-0.11059	-0.05517
0.43558	0.22403	-0.29246	-0.10176	-0.05028
0.51113	0.17226	-0.25292	-0.08596	-0.04188
0.58677	0.13724	-0.22434	-0.07442	-0.03568
0.66247	0.12016	-0.21609	-0.07063	-0.03333
0.73821	0.11320	-0.22168	-0.07206	-0.03349
0.81912	0.10718	-0.22855	-0.07374	-0.03348
0.89863	0.09604	-0.22330	-0.07020	-0.03024
0.95950	0.07867	-0.19727	-0.05850	-0.02377
0.99245	0.05261	-0.14101	-0.03587	-0.01526

Ct/s = 3.7334442E-02

Blade index 3

0.28502	0.70471	-0.33886	-0.11822	-0.06007
0.36017	0.80208	-0.49293	-0.18003	-0.09616
0.43558	0.80005	-0.60649	-0.22252	-0.11885
0.51113	0.76683	-0.69371	-0.25408	-0.13423
0.58677	0.71960	-0.75769	-0.27647	-0.14425
0.66247	0.66290	-0.79739	-0.28936	-0.14911
0.73821	0.59635	-0.80859	-0.29077	-0.14770
0.81912	0.51173	-0.78132	-0.27589	-0.13691
0.89863	0.40022	-0.68915	-0.23201	-0.10805
0.95950	0.26226	-0.51051	-0.15245	-0.05929
0.99245	0.10396	-0.26200	-0.04625	0.01168

Ct/s = 7.5016133E-02

Blade index 4

0.28502	1.09080	-0.10412	-0.04163	-0.04419
0.36017	1.08680	-0.27113	-0.10052	-0.06219
0.43558	1.12618	-0.44809	-0.16463	-0.09120
0.51113	1.12883	-0.61589	-0.22540	-0.11972
0.58677	1.10537	-0.76646	-0.27964	-0.14536
0.66247	1.06373	-0.89543	-0.32547	-0.16686
0.73821	1.00705	-0.99865	-0.36085	-0.18277
0.81912	0.92727	-1.07185	-0.38252	-0.19040
0.89863	0.81280	-1.08128	-0.37429	-0.17972
0.95950	0.64833	-0.96945	-0.31115	-0.14198
0.99245	0.42619	-0.70055	-0.18932	-0.08734

Ct/s = 6.7106366E-02

10.00000 Ctot/s = 7.2898194E-02 Lift (lbs) = 165.7915

ALft (lbs) = 145.3136 Croll = -1.1127931E-03 Cpitch = 1.5899158E-03

VORTICITY DISTRIBUTION ON BLADE SURFACE GAMA/(OMEGA*R**2)

```
 0.00771   0.01109   0.01378   0.01602   0.01786   0.01928   0.02024   0.02059   0.01970   0.01662
 0.01123
 0.00675   0.00975   0.01212   0.01410   0.01573   0.01700   0.01786   0.01820   0.01749   0.01491
 0.01021
 0.00499   0.00715   0.00888   0.01034   0.01153   0.01247   0.01312   0.01340   0.01296   0.01125
 0.00801
indx  cpin,cp(indx),phi1(i,1),phi2(i,2),dpdt
  Computed body forces and moments
F   2.7584244E-02  9.7111501E-02  2.7292609E-02
M   3.5402052E-02 -1.6857343E-03 -8.1322575E-04
Initializing AMI plot file
Wrote          684 BODG
Wrote          684 AERO
 It took    79.00000     seconds for this step.
Element             0
       Strip            1
          1 -0.1878503              2 -0.1845095               3
-0.1863916            4 -0.1916904            5 -0.2004057
          6 -0.2122656              7 -0.2296641               8
-0.2474872            9 -0.2633151
       Strip            2
          1 -0.1775673              2 -0.1607116               3
-0.1564240            4 -0.1567281            5 -0.1625054
          6 -0.1731901              7 -0.1935267               8
-0.2201638            9 -0.2524444
       Strip            3
          1 -0.1696347              2 -0.1422022               3
-0.1329200            4 -0.1291109            5 -0.1325378
          6 -0.1426349              7 -0.1653218               8
-0.1984226            9 -0.2436304
       Strip            4
          1 -0.1672843              2 -0.1366200               3
-0.1258687            4 -0.1208845            5 -0.1234300
          6 -0.1332333              7 -0.1565078               8
-0.1916651            9 -0.2409862
       Strip            5
          1  0.0000000E+00          2  0.0000000E+00           3
 0.0000000E+00        4  0.0000000E+00        5  0.0000000E+00
          6  0.0000000E+00          7  0.0000000E+00           8
 0.0000000E+00        9  0.0000000E+00


 PSIAV=   20.0000 DEG     TEND=(R/B)*PSIAV=    0.3491        2 TIME STEPS

          Pressure Coefficients
Blade Loads (Chord stations)
Radius      Cn          0.16667   0.50000   0.83333
 Blade index              1
  0.28502   0.52903  -0.37535  -0.13449  -0.06662
  0.36017   0.62639  -0.53245  -0.19403  -0.09704
  0.43558   0.65651  -0.65426  -0.23889  -0.11824
  0.51113   0.65962  -0.75533  -0.27519  -0.13494
  0.58677   0.64762  -0.83825  -0.30444  -0.14827
```

0.66247	0.62527	-0.90318	-0.32676	-0.15824
0.73821	0.59436	-0.94878	-0.34136	-0.16425
0.81912	0.55115	-0.97167	-0.34629	-0.16423
0.89863	0.48841	-0.94819	-0.32876	-0.15284
0.95950	0.39300	-0.83399	-0.26814	-0.11999
0.99245	0.25939	-0.59758	-0.16165	-0.07299

Ct/s = 0.1102443

Blade index 2

0.28502	0.26638	-0.27236	-0.08655	-0.04121
0.36017	0.27937	-0.32162	-0.10836	-0.05252
0.43558	0.25130	-0.32916	-0.10850	-0.05312
0.51113	0.22174	-0.32632	-0.10519	-0.05172
0.58677	0.20215	-0.32872	-0.10534	-0.05227
0.66247	0.19092	-0.33801	-0.10941	-0.05518
0.73821	0.18158	-0.34684	-0.11392	-0.05845
0.81912	0.16717	-0.34475	-0.11408	-0.05968
0.89863	0.14291	-0.31868	-0.10485	-0.05376
0.95950	0.10977	-0.26448	-0.08260	-0.03954
0.99245	0.07058	-0.18336	-0.04948	-0.02273

Ct/s = 5.0047409E-02

Blade index 3

0.28502	0.71380	-0.29116	-0.10974	-0.03999
0.36017	0.79282	-0.43665	-0.16378	-0.06769
0.43558	0.80386	-0.55949	-0.20609	-0.09341
0.51113	0.79240	-0.66610	-0.24267	-0.11727
0.58677	0.76565	-0.75447	-0.27306	-0.13734
0.66247	0.72578	-0.82115	-0.29549	-0.15212
0.73821	0.67317	-0.86162	-0.30764	-0.16024
0.81912	0.60127	-0.86837	-0.30510	-0.15973
0.89863	0.50380	-0.81685	-0.27793	-0.14227
0.95950	0.37841	-0.68090	-0.21444	-0.10282
0.99245	0.23420	-0.46480	-0.12165	-0.05442

Ct/s = 7.6186009E-02

Blade index 4

0.28502	1.29312	-0.16325	-0.05984	-0.04234
0.36017	1.24519	-0.33878	-0.12436	-0.07270
0.43558	1.21353	-0.50790	-0.18642	-0.10198
0.51113	1.16989	-0.66181	-0.24208	-0.12850
0.58677	1.11721	-0.79713	-0.29047	-0.15140
0.66247	1.05737	-0.91164	-0.33070	-0.17004
0.73821	0.99013	-1.00251	-0.36126	-0.18341
0.81912	0.90582	-1.06634	-0.37936	-0.18923
0.89863	0.79316	-1.07181	-0.36995	-0.17870
0.95950	0.63316	-0.96022	-0.30740	-0.14138
0.99245	0.41602	-0.69370	-0.18699	-0.08616

Ct/s = 6.9400705E-02

20.00000 Ctot/s = 7.6469600E-02 Lift (lbs) = 173.9139

ALft (lbs) = 148.4914 Croll = -5.1523442E-04 Cpitch = 1.4087392E-03

VORTICITY DISTRIBUTION ON BLADE SURFACE GAMA/(OMEGA*R**2)

```
 0.00740   0.01057   0.01299   0.01496   0.01658   0.01782   0.01867   0.01903   0.01836   0.01569
 0.01069
 0.00655   0.00933   0.01147   0.01323   0.01467   0.01579   0.01656   0.01692   0.01640   0.01415
 0.00975
 0.00482   0.00684   0.00840   0.00970   0.01076   0.01160   0.01218   0.01248   0.01217   0.01071
 0.00767
indx  cpin,cp(indx),phi1(i,1),phi2(i,2),dpdt
  Computed body forces and moments
F   2.7508253E-02  9.8291516E-02  2.7150393E-02
M   3.5526749E-02 -5.3365447E-04 -6.3004442E-03
Wrote          684 BODG
Wrote          684 AERO
 It took    87.00000     seconds for this step.
Element            0
       Strip            1
          1 -0.1857494               2 -0.1824086            3
-0.1842907           4 -0.1895895            5 -0.1983048
          6 -0.2101647               7 -0.2275632            8
-0.2453863           9 -0.2612141
       Strip            2
          1 -0.1754664               2 -0.1586107            3
-0.1543231           4 -0.1546272            5 -0.1604045
          6 -0.1710892               7 -0.1914258            8
-0.2180629           9 -0.2503435
       Strip            3
          1 -0.1675338               2 -0.1401013            3
-0.1308191           4 -0.1270100            5 -0.1304369
          6 -0.1405340               7 -0.1632209            8
-0.1963217           9 -0.2415295
       Strip            4
          1 -0.1651834               2 -0.1345191            3
-0.1237678           4 -0.1187836            5 -0.1213291
          6 -0.1311324               7 -0.1544069            8
-0.1895642           9 -0.2388853
       Strip            5
          1  0.0000000E+00           2  0.0000000E+00        3
 0.0000000E+00       4  0.0000000E+00        5  0.0000000E+00
          6  0.0000000E+00           7  0.0000000E+00        8
 0.0000000E+00       9  0.0000000E+00


PSIAV=   30.0000 DEG     TEND=(R/B)*PSIAV=    0.5236         3 TIME STEPS

          Pressure Coefficients
Blade Loads  (Chord stations)
Radius      Cn         0.16667   0.50000   0.83333
 Blade index            1
  0.28502   0.48112  -0.37215  -0.13480  -0.06974
  0.36017   0.58096  -0.53137  -0.19552  -0.10024
  0.43558   0.61912  -0.65666  -0.24176  -0.12286
  0.51113   0.63076  -0.76224  -0.27980  -0.14117
  0.58677   0.62614  -0.84977  -0.31073  -0.15590
  0.66247   0.60955  -0.91849  -0.33434  -0.16685
```

```
   0.73821   0.58265  -0.96632  -0.34956  -0.17336
   0.81912   0.54192  -0.98913  -0.35398  -0.17335
   0.89863   0.48031  -0.96303  -0.33511  -0.16030
   0.95950   0.38602  -0.84511  -0.27261  -0.12478
   0.99245   0.25462  -0.60488  -0.16441  -0.07538
Ct/s =   0.1178146
 Blade index            2
   0.28502   0.28400  -0.28014  -0.09006  -0.04194
   0.36017   0.30252  -0.34079  -0.11306  -0.05325
   0.43558   0.28532  -0.36706  -0.11995  -0.05570
   0.51113   0.26544  -0.38363  -0.12407  -0.05726
   0.58677   0.24906  -0.39770  -0.12894  -0.05989
   0.66247   0.23423  -0.40814  -0.13367  -0.06292
   0.73821   0.21748  -0.41023  -0.13580  -0.06476
   0.81912   0.19471  -0.39800  -0.13232  -0.06373
   0.89863   0.16398  -0.36278  -0.11974  -0.05681
   0.95950   0.12616  -0.30097  -0.09428  -0.04268
   0.99245   0.08148  -0.20919  -0.05637  -0.02531
Ct/s =   5.6159534E-02
 Blade index            3
   0.28502   0.80267  -0.27378  -0.10105  -0.03344
   0.36017   0.88612  -0.42546  -0.15735  -0.06735
   0.43558   0.88637  -0.55292  -0.20181  -0.09581
   0.51113   0.85811  -0.66053  -0.23890  -0.11817
   0.58677   0.81572  -0.74822  -0.26882  -0.13509
   0.66247   0.76440  -0.81514  -0.29096  -0.14685
   0.73821   0.70540  -0.85919  -0.30406  -0.15301
   0.81912   0.63223  -0.87613  -0.30500  -0.15180
   0.89863   0.53956  -0.84495  -0.28457  -0.13654
   0.95950   0.42215  -0.73511  -0.22907  -0.10332
   0.99245   0.27473  -0.52273  -0.13723  -0.06186
Ct/s =   7.1935482E-02
 Blade index            4
   0.28502   1.09161  -0.18593  -0.05930  -0.03431
   0.36017   1.10507  -0.34700  -0.11954  -0.06517
   0.43558   1.09714  -0.50394  -0.17775  -0.09400
   0.51113   1.07485  -0.65050  -0.23214  -0.12052
   0.58677   1.03996  -0.78175  -0.28046  -0.14399
   0.66247   0.99450  -0.89436  -0.32118  -0.16340
   0.73821   0.93907  -0.98483  -0.35261  -0.17768
   0.81912   0.86531  -1.04940  -0.37179  -0.18460
   0.89863   0.76194  -1.05625  -0.36405  -0.17511
   0.95950   0.61004  -0.94686  -0.30294  -0.13877
   0.99245   0.40126  -0.68425  -0.18409  -0.08459
Ct/s =   7.0464410E-02
   30.00000    Ctot/s =   7.9093501E-02 Lift (lbs) =    179.8814
 ALft (lbs) =    151.9791     Croll =   8.2993181E-05 Cpitch =   1.7146990E-03
```

Listing 2. Example Output File stdout

This file has been abbreviated to only three of the fifteen steps called for in the input file.

The next output file is generated to summarize the local blade loading. Dimensional loads (in pounds per inch span) and non-dimensional circulation are tabulated by fraction of rotor radius for the reference blade at each time (or azimuth) step.

```
TITLE = "RWF: Blade loads"
VARIABLES = "r/R", "l, Lb/in.", Gamma
ZONE Z=   10.00000    , I=         11
 0.285    0.55  0.0077
 0.360    0.97  0.0111
 0.435    1.42  0.0138
 0.510    1.92  0.0160
 0.586    2.43  0.0179
 0.661    2.95  0.0193
 0.737    3.43  0.0202
 0.818    3.85  0.0206
 0.897    4.02  0.0197
 0.958    3.61  0.0166
 0.991    2.52  0.0112
ZONE Z=   20.00000    , I=         11
 0.285    0.59  0.0074
 0.360    1.01  0.0106
 0.435    1.45  0.0130
 0.510    1.92  0.0150
 0.586    2.40  0.0166
 0.661    2.87  0.0178
 0.737    3.32  0.0187
 0.818    3.72  0.0190
 0.897    3.90  0.0184
 0.958    3.54  0.0157
 0.991    2.49  0.0107
ZONE Z=   30.00000    , I=         11
 0.285    0.64  0.0074
 0.360    1.10  0.0106
 0.435    1.57  0.0131
 0.510    2.07  0.0152
 0.586    2.58  0.0169
 0.661    3.08  0.0182
 0.737    3.55  0.0191
 0.818    3.96  0.0195
 0.897    4.13  0.0187
 0.958    3.73  0.0160
 0.991    2.61  0.0108
ZONE Z=   40.00000    , I=         11
 0.285    0.68  0.0072
 0.360    1.14  0.0103
 0.435    1.62  0.0128
 0.510    2.13  0.0148
 0.586    2.64  0.0165
 0.661    3.15  0.0179
 0.737    3.62  0.0188
 0.818    4.04  0.0192
 0.897    4.21  0.0185
 0.958    3.81  0.0158
 0.991    2.67  0.0108
```

```
ZONE Z=   50.00000   , I=   11
 0.285    0.70  0.0070
 0.360    1.17  0.0101
 0.435    1.65  0.0124
 0.510    2.16  0.0144
 0.586    2.68  0.0161
 0.661    3.19  0.0175
 0.737    3.67  0.0185
 0.818    4.09  0.0189
 0.897    4.28  0.0183
 0.958    3.87  0.0156
 0.991    2.71  0.0107
ZONE Z=   60.00000   , I=   11
 0.285    0.71  0.0068
 0.360    1.18  0.0097
 0.435    1.64  0.0119
 0.510    2.13  0.0138
 0.586    2.64  0.0154
 0.661    3.16  0.0168
 0.737    3.64  0.0179
 0.818    4.08  0.0184
 0.897    4.27  0.0179
 0.958    3.87  0.0154
 0.991    2.72  0.0105
ZONE Z=   69.99999   , I=   11
 0.285    0.71  0.0065
 0.360    1.16  0.0092
 0.435    1.59  0.0112
 0.510    2.04  0.0129
 0.586    2.52  0.0144
 0.661    3.02  0.0158
 0.737    3.51  0.0169
 0.818    3.97  0.0176
 0.897    4.19  0.0173
 0.958    3.82  0.0149
 0.991    2.69  0.0102
ZONE Z=   79.99999   , I=   11
 0.285    0.70  0.0063
 0.360    1.12  0.0088
 0.435    1.49  0.0103
 0.510    1.86  0.0116
 0.586    2.28  0.0129
 0.661    2.77  0.0143
 0.737    3.28  0.0156
 0.818    3.76  0.0165
 0.897    4.02  0.0164
 0.958    3.70  0.0143
 0.991    2.61  0.0099
ZONE Z=   89.99999   , I=   11
 0.285    0.69  0.0061
 0.360    1.07  0.0083
 0.435    1.35  0.0094
 0.510    1.62  0.0101
```

```
  0.586     1.98  0.0112
  0.661     2.49  0.0128
  0.737     3.01  0.0143
  0.818     3.51  0.0154
  0.897     3.81  0.0155
  0.958     3.54  0.0137
  0.991     2.51  0.0094
 ZONE Z=    99.99998     , I=          11
  0.285     0.68  0.0061
  0.360     1.04  0.0081
  0.435     1.29  0.0090
  0.510     1.53  0.0095
  0.586     1.89  0.0107
  0.661     2.39  0.0124
  0.737     2.90  0.0138
  0.818     3.41  0.0150
  0.897     3.72  0.0152
  0.958     3.47  0.0135
  0.991     2.47  0.0093
 ZONE Z=    110.0000     , I=          11
  0.285     0.70  0.0064
  0.360     1.09  0.0087
  0.435     1.40  0.0099
  0.510     1.74  0.0110
  0.586     2.15  0.0123
  0.661     2.63  0.0138
  0.737     3.13  0.0151
  0.818     3.60  0.0160
  0.897     3.87  0.0160
  0.958     3.58  0.0140
  0.991     2.54  0.0096
 ZONE Z=    120.0000     , I=          11
  0.285     0.71  0.0067
  0.360     1.10  0.0090
  0.435     1.44  0.0105
  0.510     1.83  0.0119
  0.586     2.31  0.0135
  0.661     2.85  0.0152
  0.737     3.36  0.0165
  0.818     3.81  0.0172
  0.897     4.02  0.0168
  0.958     3.68  0.0146
  0.991     2.60  0.0100
 ZONE Z=    130.0000     , I=          11
  0.285     0.69  0.0069
  0.360     1.08  0.0092
  0.435     1.46  0.0110
  0.510     1.91  0.0127
  0.586     2.44  0.0147
  0.661     3.00  0.0165
  0.737     3.51  0.0176
  0.818     3.93  0.0181
  0.897     4.10  0.0176
```

```
 0.958    3.74  0.0151
 0.991    2.64  0.0104
ZONE Z=   140.0000    , I=        11
 0.285    0.67  0.0071
 0.360    1.07  0.0097
 0.435    1.48  0.0117
 0.510    1.94  0.0135
 0.586    2.46  0.0154
 0.661    3.04  0.0172
 0.737    3.55  0.0184
 0.818    3.96  0.0188
 0.897    4.11  0.0181
 0.958    3.74  0.0155
 0.991    2.64  0.0106
ZONE Z=   150.0000    , I=        11
 0.285    0.66  0.0075
 0.360    1.06  0.0102
 0.435    1.47  0.0123
 0.510    1.92  0.0141
 0.586    2.43  0.0159
 0.661    2.99  0.0177
 0.737    3.51  0.0189
 0.818    3.93  0.0193
 0.897    4.08  0.0185
 0.958    3.70  0.0158
 0.991    2.61  0.0108
```

Listing 3. Example Output File cn0.out

The next output file is generated to list each blade normal force coefficient. One of these files is generated for each blade of the rotor system. Each line in this file starts with the blade azimuth, followed by the normal force coefficient for each of the specified spanwise panels of the blade, followed by the blade total effective C_T/σ. A line is added to these files for each time (or azimuth) step.

```
Cn file for blade           1
 10.  0.6170  0.7207  0.7533  0.7558  0.7409  0.7138  0.6764  0.6233  0.5457  0.4324  0.2830
0.1121
 20.  0.5290  0.6264  0.6565  0.6596  0.6476  0.6253  0.5944  0.5511  0.4884  0.3930  0.2594
0.1102
 30.  0.4811  0.5810  0.6191  0.6308  0.6261  0.6095  0.5826  0.5419  0.4803  0.3860  0.2546
0.1178
 40.  0.4338  0.5294  0.5693  0.5848  0.5850  0.5734  0.5515  0.5160  0.4599  0.3713  0.2454
0.1207
 50.  0.3953  0.4872  0.5278  0.5460  0.5500  0.5427  0.5251  0.4940  0.4423  0.3583  0.2373
0.1226
 60.  0.3628  0.4488  0.4865  0.5045  0.5109  0.5079  0.4954  0.4696  0.4233  0.3446  0.2288
0.1219
 70.  0.3385  0.4167  0.4469  0.4602  0.4667  0.4676  0.4610  0.4424  0.4029  0.3302  0.2199
0.1183
 80.  0.3207  0.3892  0.4059  0.4086  0.4124  0.4182  0.4206  0.4113  0.3798  0.3142  0.2101
0.1113
 90.  0.3096  0.3666  0.3652  0.3529  0.3549  0.3728  0.3836  0.3808  0.3573  0.2988  0.2008
0.1027
100.  0.3100  0.3608  0.3520  0.3353  0.3408  0.3618  0.3724  0.3722  0.3515  0.2952  0.1987
```

```
0.0993
110.  0.3339  0.3912  0.3945  0.3920  0.3993  0.4077  0.4100  0.4016  0.3723  0.3092  0.2074
0.1064
120.  0.3604  0.4182  0.4284  0.4343  0.4470  0.4590  0.4569  0.4387  0.3990  0.3279  0.2192
0.1120
130.  0.3880  0.4479  0.4671  0.4821  0.5000  0.5099  0.5011  0.4736  0.4246  0.3463  0.2310
0.1153
140.  0.4290  0.4970  0.5209  0.5341  0.5452  0.5534  0.5406  0.5058  0.4490  0.3642  0.2425
0.1161
150.  0.4905  0.5601  0.5790  0.5857  0.5894  0.5907  0.5769  0.5379  0.4741  0.3828  0.2546
0.1148
```

Listing 4. Example Output File **cn1.out**

In addition to the blade load files, a provision for output of the velocities in a space grid has been included. The array of points in space is specified in a grid data file titled **GRID.DAT**. An example of such a file is given here. Space is nondimensionalized by rotor radius. The first line of the file contains the interger dimensions of the space array. In the example below the file contains 15 × 12 localtions.

```
15 12
0.20000  0.00000  0.08800
0.40000  0.00000  0.08800
0.50000  0.00000  0.08800
0.60000  0.00000  0.08800
0.70000  0.00000  0.08800
0.74000  0.00000  0.08800
0.78000  0.00000  0.08800
0.82000  0.00000  0.08800
0.86000  0.00000  0.08800
0.90000  0.00000  0.08800
0.94000  0.00000  0.08800
0.98000  0.00000  0.08800
1.02000  0.00000  0.08800
1.04000  0.00000  0.08800
1.10000  0.00000  0.08800
0.17321  0.10000  0.08800
0.34641  0.20000  0.08800
0.43301  0.25000  0.08800
0.51962  0.30000  0.08800
0.60622  0.35000  0.08800
0.64086  0.37000  0.08800
0.67550  0.39000  0.08800
0.71014  0.41000  0.08800
0.74478  0.43000  0.08800
0.77942  0.45000  0.08800
0.81406  0.47000  0.08800
0.84870  0.49000  0.08800
0.88335  0.51000  0.08800
0.90067  0.52000  0.08800
0.95263  0.55000  0.08800
```

Extended list of locations abbreviated

```
0.17321  -0.10000  0.08800
0.34641  -0.20000  0.08800
0.43301  -0.25000  0.08800
0.51962  -0.30000  0.08800
0.60622  -0.35000  0.08800
0.64086  -0.37000  0.08800
0.67550  -0.39000  0.08800
0.71014  -0.41000  0.08800
0.74478  -0.43000  0.08800
0.77942  -0.45000  0.08800
0.81406  -0.47000  0.08800
0.84870  -0.49000  0.08800
0.88335  -0.51000  0.08800
0.90067  -0.52000  0.08800
0.95263  -0.55000  0.08800
```

Listing 5. Example Grid Data Input File **GRID.DAT**

The result of setting the input parameter `DOGRID` to be true and providing the file **GRID.DAT** will be a general velocity file containing a listing of the grid locations from file **GRID.DAT** and followed by a list of u, v, w velocities (nindimensionalized by ΩR) for each time (or azimuth) step. An example of the output file (**GPVEL.DAT**) is shown below.

In this example output file the data is separated into time step zones. The X, Y, Z locations change for each time step in this example. This location change is controlled by the `INERTIAL` flag in the input file. If the `INERTIAL` value is true, as in this example, the hub as well as the velocity grid will be translated through the onset flow, in inertial space.

```
TITLE = "RWF-LaRC (Berry)"
VARIABLES =  "X","Y","Z","U","V","W"
 ZONE T="RWF               1", F=POINT, I=          15, J=          13
   0.200000    0.000000    0.088000    0.001289   -0.002308   -0.006725
   0.400000    0.000000    0.088000    0.001522   -0.009247   -0.018324
   0.500000    0.000000    0.088000    0.000839   -0.009811   -0.020396
   0.600000    0.000000    0.088000   -0.000275   -0.009400   -0.021862
   0.700000    0.000000    0.088000   -0.002582   -0.008575   -0.023007
   0.740000    0.000000    0.088000   -0.004138   -0.008232   -0.023379
   0.780000    0.000000    0.088000   -0.006299   -0.007947   -0.023665
   0.820000    0.000000    0.088000   -0.009364   -0.007815   -0.023640
   0.860000    0.000000    0.088000   -0.013562   -0.007928   -0.022854
   0.900000    0.000000    0.088000   -0.019075   -0.008402   -0.020292
   0.940000    0.000000    0.088000   -0.024609   -0.009005   -0.013972
   0.980000    0.000000    0.088000   -0.025824   -0.008678   -0.003669
   1.020000    0.000000    0.088000   -0.020009   -0.006668    0.004749
   1.040000    0.000000    0.088000   -0.016111   -0.005436    0.006585
   1.100000    0.000000    0.088000   -0.007625   -0.002703    0.006461
   0.173210    0.100000    0.088000   -0.004052   -0.005021   -0.001807
   0.346410    0.200000    0.088000   -0.004605   -0.007949    0.004585
   0.433010    0.250000    0.088000   -0.004689   -0.006515    0.005900
   0.519620    0.300000    0.088000   -0.004490   -0.004911    0.005950
   0.606220    0.350000    0.088000   -0.004152   -0.003446    0.005136
   0.640860    0.370000    0.088000   -0.003993   -0.002921    0.004648
   0.675500    0.390000    0.088000   -0.003825   -0.002436    0.004098
   0.710140    0.410000    0.088000   -0.003647   -0.001993    0.003506
```

0.744780	0.430000	0.088000	-0.003457	-0.001595	0.002890
0.779420	0.450000	0.088000	-0.003260	-0.001248	0.002265
0.814060	0.470000	0.088000	-0.003055	-0.000953	0.001644
0.848700	0.490000	0.088000	-0.002846	-0.000712	0.001039
0.883350	0.510000	0.088000	-0.002639	-0.000525	0.000456
0.900670	0.520000	0.088000	-0.002538	-0.000451	0.000173
0.952630	0.550000	0.088000	-0.002244	-0.000299	-0.000634

Extended list of data abbreviated

0.173210	-0.100000	0.088000	-0.005325	0.001856	-0.003833
0.346410	-0.200000	0.088000	-0.005924	0.000975	-0.005251
0.433010	-0.250000	0.088000	-0.005657	0.000273	-0.004949
0.519620	-0.300000	0.088000	-0.005048	-0.000311	-0.004642
0.606220	-0.350000	0.088000	-0.004336	-0.000720	-0.004396
0.640860	-0.370000	0.088000	-0.004050	-0.000833	-0.004306
0.675500	-0.390000	0.088000	-0.003769	-0.000917	-0.004221
0.710140	-0.410000	0.088000	-0.003496	-0.000975	-0.004140
0.744780	-0.430000	0.088000	-0.003233	-0.001006	-0.004067
0.779420	-0.450000	0.088000	-0.002979	-0.001014	-0.004006
0.814060	-0.470000	0.088000	-0.002739	-0.001001	-0.003963
0.848700	-0.490000	0.088000	-0.002511	-0.000967	-0.003940
0.883350	-0.510000	0.088000	-0.002295	-0.000916	-0.003943
0.900670	-0.520000	0.088000	-0.002192	-0.000883	-0.003955
0.952630	-0.550000	0.088000	-0.001908	-0.000761	-0.004037
0.200000	0.000000	0.088000	0.001289	-0.002308	-0.006725
0.400000	0.000000	0.088000	0.001522	-0.009247	-0.018324
0.500000	0.000000	0.088000	0.000839	-0.009811	-0.020396
0.600000	0.000000	0.088000	-0.000275	-0.009400	-0.021862
0.700000	0.000000	0.088000	-0.002582	-0.008575	-0.023007
0.740000	0.000000	0.088000	-0.004138	-0.008232	-0.023379
0.780000	0.000000	0.088000	-0.006299	-0.007947	-0.023665
0.820000	0.000000	0.088000	-0.009364	-0.007815	-0.023640
0.860000	0.000000	0.088000	-0.013562	-0.007928	-0.022854
0.900000	0.000000	0.088000	-0.019075	-0.008402	-0.020292
0.940000	0.000000	0.088000	-0.024609	-0.009005	-0.013972
0.980000	0.000000	0.088000	-0.025824	-0.008678	-0.003669
1.020000	0.000000	0.088000	-0.020009	-0.006668	0.004749
1.040000	0.000000	0.088000	-0.016111	-0.005436	0.006585
1.100000	0.000000	0.088000	-0.007625	-0.002703	0.006461
ZONE T="RWF	2",	F=POINT, I=	15, J=		13
0.119825	0.000000	0.092202	-0.004792	0.000353	-0.002329
0.319825	0.000000	0.092202	0.003266	-0.004925	-0.008707
0.419825	0.000000	0.092202	0.003194	-0.005678	-0.012315
0.519825	0.000000	0.092202	0.002085	-0.004967	-0.014984
0.619825	0.000000	0.092202	-0.000005	-0.003988	-0.016971
0.659825	0.000000	0.092202	-0.001203	-0.003689	-0.017657
0.699825	0.000000	0.092202	-0.002692	-0.003500	-0.018329
0.739825	0.000000	0.092202	-0.004580	-0.003470	-0.018957
0.779825	0.000000	0.092202	-0.007007	-0.003647	-0.019502
0.819825	0.000000	0.092202	-0.010200	-0.004094	-0.019753
0.859825	0.000000	0.092202	-0.014339	-0.004857	-0.019267

0.899825	0.000000	0.092202	-0.019486	-0.005946	-0.017060
0.939825	0.000000	0.092202	-0.024379	-0.007032	-0.011422
0.959825	0.000000	0.092202	-0.025602	-0.007278	-0.007100
1.019825	0.000000	0.092202	-0.019883	-0.005614	0.005162
0.093035	0.100000	0.092202	-0.005518	-0.001023	-0.002140
0.266235	0.200000	0.092202	-0.001116	-0.008566	0.001889
0.352835	0.250000	0.092202	-0.000449	-0.010695	0.004714
0.439445	0.300000	0.092202	-0.000376	-0.011144	0.006764
0.526045	0.350000	0.092202	-0.000741	-0.010438	0.007543
0.560685	0.370000	0.092202	-0.000998	-0.009920	0.007482
0.595325	0.390000	0.092202	-0.001315	-0.009286	0.007219
0.629965	0.410000	0.092202	-0.001684	-0.008538	0.006771
0.664605	0.430000	0.092202	-0.002085	-0.007674	0.006161
0.699245	0.450000	0.092202	-0.002485	-0.006701	0.005418
0.733885	0.470000	0.092202	-0.002825	-0.005642	0.004582
0.768525	0.490000	0.092202	-0.003044	-0.004563	0.003690
0.803175	0.510000	0.092202	-0.003108	-0.003556	0.002782
0.820495	0.520000	0.092202	-0.003084	-0.003109	0.002335
0.872455	0.550000	0.092202	-0.002861	-0.002058	0.001060

Extended list of data abbreviated

ZONE T="RWF 15", F=POINT, I= 15, J= 13

-4.570419	0.000000	0.338007	0.000428	-0.000002	-0.000064
-4.370419	0.000000	0.338007	0.000485	-0.000003	-0.000074
-4.270419	0.000000	0.338007	0.000517	-0.000003	-0.000080
-4.170419	0.000000	0.338007	0.000553	-0.000003	-0.000087
-4.070419	0.000000	0.338007	0.000592	-0.000003	-0.000095
-4.030419	0.000000	0.338007	0.000609	-0.000003	-0.000099
-3.990419	0.000000	0.338007	0.000627	-0.000004	-0.000102
-3.950419	0.000000	0.338007	0.000645	-0.000004	-0.000106
-3.910419	0.000000	0.338007	0.000665	-0.000004	-0.000111
-3.870419	0.000000	0.338007	0.000685	-0.000004	-0.000115
-3.830419	0.000000	0.338007	0.000705	-0.000004	-0.000120
-3.790419	0.000000	0.338007	0.000727	-0.000004	-0.000125
-3.750419	0.000000	0.338007	0.000750	-0.000004	-0.000130
-3.730419	0.000000	0.338007	0.000762	-0.000005	-0.000133
-3.670419	0.000000	0.338007	0.000799	-0.000005	-0.000141
-4.597209	0.100000	0.338007	0.000420	-0.000015	-0.000062
-4.424009	0.200000	0.338007	0.000465	-0.000033	-0.000069
-4.337409	0.250000	0.338007	0.000489	-0.000044	-0.000073
-4.250799	0.300000	0.338007	0.000515	-0.000056	-0.000077
-4.164199	0.350000	0.338007	0.000542	-0.000070	-0.000081
-4.129559	0.370000	0.338007	0.000553	-0.000077	-0.000083
-4.094919	0.390000	0.338007	0.000565	-0.000083	-0.000085
-4.060279	0.410000	0.338007	0.000576	-0.000090	-0.000087
-4.025639	0.430000	0.338007	0.000588	-0.000097	-0.000089
-3.990999	0.450000	0.338007	0.000600	-0.000105	-0.000091
-3.956359	0.470000	0.338007	0.000612	-0.000113	-0.000094
-3.921719	0.490000	0.338007	0.000625	-0.000122	-0.000096
-3.887069	0.510000	0.338007	0.000637	-0.000131	-0.000098
-3.869749	0.520000	0.338007	0.000644	-0.000135	-0.000099

-3.817789	0.550000	0.338007	0.000663	-0.000150	-0.000103

Extended list of data abbreviated

Listing 6. Example Grid Data Output File **GPVEL.DAT**

6 Installation Notes

The code **RWF** was developed using a software development environment which included a FORTRAN-77 compiler with Digital Equipment's VAX extensions. The extension which may prove troublesome are the "`do—enddo`" constructs and the "`namelist`" function mentioned above. Work is underway to improve "portability."

The UNIX source version of **RWF** is provided with modules and common blocks archived with the "`tar`" utility. The "`make`" utility can be used to compile the module library and the main program. The `makefile` files in the main and `rwsubs` directory are provided in the archive. The `makefile` may need to be modified to use the local compiler option conventions.

6.1 Directory Structure

Two subdirectories are used for **RWF** . One is for the common block files, and the other is for the module source and object library files. Parameter files which are used to size the commons are left in the main directory and are included by "`include`" statements in the common blocks. The names of the two directories are: **commons** and **rwsubs**.

The files provided in the `tar` archive are put into: a main directory, and the two sub-directories. The main directory contains the main program file, **wingg.f** as well as the parameter files: **fparm.par** and **bparm.par**. The **bparm.par** file sets up the number of blades for the rotor. Three additional blade parameter files are included for 2, 3, or four blades, but one must be renamed to *THE* **bparm.par** file name before compilation. The commonsi directory contains files of the form **xxx.com**. These files are the common blocks used by **RWF** . The **rwsubs.a** file contains the modules needed by **RWF** and are described in the section below.

6.2 Module Description

The modules which are part of **RWF** are listed below. Not all modules are "active" in the current code; inactive modules are indicated by $\star$.

$\star$ 1. `aiot`—Modified Biot-Savart module.

2. `biot`—Biot-Savart module, computes the velocity at a point due to a specified vortex filament segment.

3. `biotf`—Biot-Savart module to compute the velocity at a point due to a collection of vortex filament segments.

4. `biott`—Biot-Savart module to compute the velocity at a point due to a semi-infinite "trailing" vortex filament.

5. `blade`—Module which builds the rotor blade geometries.

6. **body**—Module which reads in the body geometry file and computes the panel reference data arrays.

7. **calcp**—Module which calculates the C_P distribution on the body panels.

⋆ 8. **calmu**—Module which calculates a contribution to the potential value at a point.

⋆ 9. **calsi**—Module which calculates a contribution to the potential value at a point.

10. **cell**—Biot-Savart calculation for the influence of a doublet panel.

11. **conv**—Converts independent x, y, z arrays into a single indexed array.

12. **cycmat**—Module to compute the cyclic pitch transformation matrix (transformation from no-flapping to no-feathering plane).

13. **decomp**—Module to perform LU decomposition on the coefficient matrix.

⋆ 14. **e**—Elliptic function for potential calculation.

15. **eul**—Computation of the convected wake geometry.

⋆ 16. **expa**—Sub-module for the potential calculation scheme.

⋆ 17. **expo**—Sub-module for the potential calculation scheme.

⋆ 18. **fmnk**—Sub-module for the potential calculation scheme.

19. **gauss**—Gaussian integration for the wake geometry convection method.

20. **getcard**—Reads in a body geometry file record.

21. **grid**—Field point velocity routine.

22. **hcell**—Biot-Savart calculation for the influence of a doublet panel.

⋆ 23. **hmnk**—Sub-module for the potential calculation scheme.

24. **hsell**—Modified Biot-Savart calculation for the influence of a doublet panel.

25. **huntl**—Sub-module for the **spline** module.

26. **index**—Compute a panel geometry index from array indices or compute array indeces from panel index.

27. **integ**—Module to perform the integration of convection velocities on the vortex lattice geometry.

28. **loc2ref**—Converts local panel coordinates to world-reference coordinates.

29. `matrix`—Computes the general influence coefficient matrices for both the rotor system and the body.

30. `mvind`—Modified induced velocity module.

31. `nolift`—Computes elements for the solution to the source panels. (Hess)

32. `normals`—Sub-module to compute the normal vector to a panel.

33. **quad**—Compute panel dependent quantities.

34. `ref2loc`—Converts world-reference coordinates to local panel coordinates.

35. `rob`—Computes the effects of the rotor-induced velocities at the body panel centroids.

36. `rotate`—Module to effect a general rotation (uses the rotation matrix established by `setrot`.)

⋆37. `sell`—Modified Biot-Savart calculation for the influence of a doublet panel.

38. `setrot`—Computes the elements of the general rotation matrix.

39. `solve`—Back-substitution module using the LU decomposition of `decomp`.

40. `spline`—Recasts values along a line to specified points using a cubic-spline interpolating routine. (Recipes)

41. `splint`—Establishes the coefficients for the `spline` module. (Recipes)

42. `tcell`—Biot-Savart calculation for the influence of a doublet panel with an extended (trailing) downstream edge.

43. `transf`—Module translates and rotates the geometry system in inertial space, computing new geometries at a given time step.

44. `vfind`—Computes induced velocities from the UTRC generalized wake routines.

45. `vfmnlf`—Computes the velocity at a point due to a single non-lifting source panel. (Hess)

46. `vind`—Module to compute the velocity induced by the wake.

47. **vindbc**—Computes the velocity induced at a panel centroid (boundary condition) by the entire vortex lattice.

48. **vindgp**—Computes the field velocity at an arbitrary point due to the entire system of singularities.

49. **vindr**—Computes the field velocities at a point due to the entire system plus the trailed vortex starters.

50. `vmindf`—Module to use a "mean" induced velocity as the induced velocity at the blade elements.

51. **xform4**--Transformation coefficients from global to panel local coordinates. (**Hess**)

6.3 Matrix Solution Options

Three sets of matrix solution routines can be used by **RWF** . Two routine sets are provided with the source and a third is provided by a vender-specific math library. The table below summarizes the routines.

Routine Description	Generic	Recipes	VECLIB
Perform LU decomposition	**DECOMP**	**ludcmp**	**SGEFA**
Perform back-substitution	**SOLVE**	**lubksb**	**SGESL**

Table 2. Matrix manipulation routines

The generic routines are not restricted. The routines labled 'recipes' are copyrighted by Numerical Recipes Software. The **VECLIB** routines are specific to the UNIX implimentation of a vector processing mathematical library on CONVEX 200 series machines.

6.4 Creating RWF

RWF can be provided in two forms; one for the UNIX environment and another for the VMS (Digital Equipment Corperation's VAX proprietary operating system) environment. Although similar, these operating systems require slightly different installations.

6.4.1 UNIX Environment

Step 1. Create a main directory (name of your choice.)

Step 2. Create two subdirectories; **rwsubs** and **commons**

Step 3. Change directory, **cd**, to the main directory.

Step 4. **tar -xv** to move the contents of the tape archive into the main, commons, and subroutines directories.

Step 5. Modify the **bparm.par** file to the correct number of blades for the code.

Step 6. In the **rwsubs.a** file is an input file, **makefile**, for the **make** utility. Run **make**. This will create a subroutine library file, **rwlib.a**, file. (Some systems require **ranlib** utility to make this file accessable to the linker.)

Step 7. Modify the main program file (**wingf.f**), to call the correct matrix manipulation subroutines (see the in-line comments.) The program also contains directory descriptors for the plot and debug files. These directory descriptors must exist.

Step 8. Create a "scratch" target directory to match the file paths from step 7. Typically this directory is **/scr/user** where the **user** refers to you.

Step 9. Compile the program. A **makefile** is provided in the main directory to compile the program main file, **wingg.f**, with the library file make in step 6.

Step 10. Create (or modify) the input files according to the instructions in section 4.

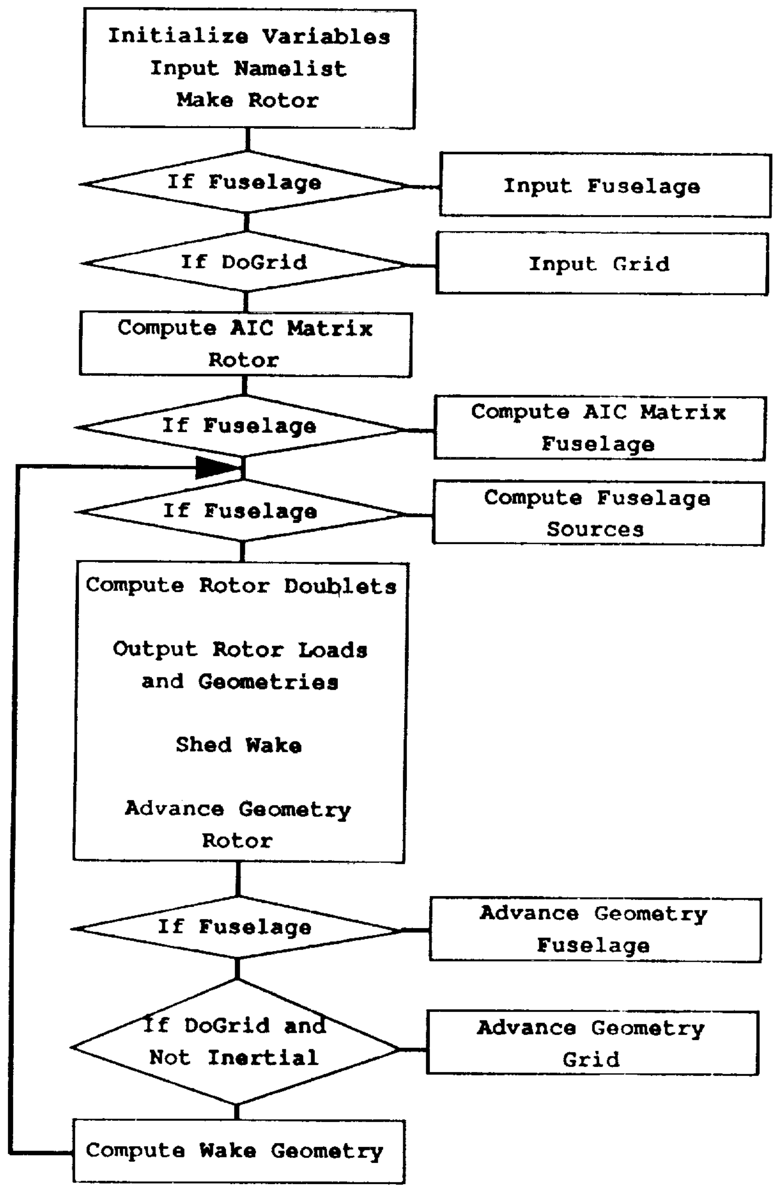
Step 11. Run the program and ponder the results.

6.4.2 VMS Environment

These instructions will be added as the code is re-ported to VMS. Currently the code exceeds the page sizes allowed on the site specific VMS machine here.

6.4.3 Silicon Graphics Environment

An output file containing geometry, pressure and local velocity in a binary format will be generated. The format of this file is tailored specifically for a third-party graphics code which runs on the Silicon Graphics workstation. The graphics code, `OMNI3D`, is a product of Analytical Methods, Inc. The output file is **ami.PLT** and can be input directly to this code.



7 Cautions

- Check the dimensions of the panels which can be specified on the blade surface carefully. Only a cursory check of dimensionality is performed.

- Check the blade parameter statement, **bparms.par**, for the maximum length of the wake, **iw**, and insure that you do not ask for too many wake time steps.

- Insure that the plotting azimuth is an even multiple of the azimuthal step increment.

8 References

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16. Abstract

(Rotor-Wake-Fuselage)

The RWF computer code has been developed from first principles to compute the aerodynamics associated with the complex flow field of helicopter configurations. The code is sized for a single, multi-bladed main rotor and any configuration of non-lifting fuselage. The mathematical model for the Rotor Wake Fuselage code is based on the integration of the momentum equations and Green's theorem. The unknowns in the problem are the strengths of prescribed singularity distributions on the boundaries of the flow. For the body (fuselage) a surface of constant strength source panels is used. For the rotor blades and rotor wake a surface of constant strength doublet panels is used. The mean camber line of the rotor airfoil is partitioned into surface panels. The no-flow boundary condition at the panel centroids is modified at each azimuthal step to account for rotor blade cyclic pitch variation. The geometry of the rotor wake is computed at each time step of the solution. The code produces rotor and fuselage surface pressures, as well as the complex geometry of the evolving rotor wake.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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